# Appendix A – Tolend Road Pavement Analysis

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# Tolend Road Pavement Analysis

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## Tolend Road Pavement Analysis Summary

This document presents a summary of pavement analysis performed on the Tolend Road pavement section, an assessment of remedial repair options, and suggestions for future QC/QA to prevent similar situations in the future.

### General Assessment

The Tolend Road pavement began to exhibit significant cracking along the longitudinal and transverse construction joints and in the wheel path within a few months of construction. The cracking along the construction joints, although not preferable, is not surprising given the relative difficulty in achieving adequate compaction along cold joints. The cracking in the wheel path and rutting that have been measured are more of a concern because they indicate a structural deficiency in the pavement structure and/or a material related problem.

There are likely both material related and construction related issues that contributed to the cracking observed on Tolend road. The construction issues are addressed in the Underwood Engineering report. The bullet points below discuss several materials related factors that have the potential, either individually or in combination, to cause the distress observed along the roadway.

- *Mix Design*: the asphalt mixture used for the binder course was a 75 gyration design. A 75 gyration design (as opposed to a 50 gyration design), is intended for high volume roadways and is typically used on interstate pavements in NH. A 75 gyration design will have a lower asphalt content and therefore may be more difficult to compact in the field (leading to lower in-place densities) and may be more prone to cracking (due to lower asphalt content). A 50 gyration design would be more appropriate for Tolend Road.
- *In-place density:* in general, the in-place density of the asphalt was satisfactory along the pavement and met the density specification in most locations. However, low in-place densities were measured at several locations; areas of low density will be weaker and therefore more susceptible to rutting, cracking, and moisture intrusion. This includes locations along the construction joints and some locations in the lanes.
- *Asphalt content*: a low asphalt content will cause the asphalt layer to be more brittle and therefore more susceptible to cracking. The average asphalt content along the road was close to the target and the measurements were all within specification. However, there were several locations where asphalt contents were measured to be 0.2% lower than the target asphalt content, which could cause a difference in performance.
- *Mixture gradation*: a finer gradation (larger amount of small particles) will cause the asphalt layer to be more brittle because more asphalt is needed to coat the aggregate particles (larger surface area), reducing the effective asphalt content available to bind the aggregate together and provide resistance to fatigue cracking. More than half of the core samples taken failed the mixture gradation tolerance for the #200 sieve (fines).
- *Asphalt grade and RAP*: a PG 64-28 grade asphalt was specified for this project and the mixture contained approximately 20% by weight of reclaimed asphalt pavement (RAP). Two cores were sent to a lab for extraction and recovery of the asphalt and subsequent testing. The recovered asphalt tests measured the grades to be PG 82-22 and PG 76-22 from the two cores, respectively. These are stiffer than expected given the virgin PG grade and the percentage of

RAP used in the mixture. This could be an indication that a very stiff RAP was used or that the mixture was produced at higher temperatures that could have caused additional aging of the mixture during production and placement. A stiff RAP or additional aging could cause the mixture to be more brittle and therefore more susceptible to cracking. There is not a specification for the PG grade of asphalt extracted and recovered from cores.

- *Base course gradation*: the aggregates that were used in the base and subbase courses did not meet the specified gradations for many of the samples taken. The gradations were on the fine side of the specifications, which will decrease the stiffness of the aggregate base and potentially increase the susceptibility to cracking and rutting.

## Pavement Analysis

A pavement analysis was performed to assess relative differences in expected performance between the approved and the constructed pavement structures. Several assumptions were made in the analysis and therefore the actual number of traffic loads (18k axle loadings) may not be reliable. However, the relative differences in the values can be used to estimate expected differences in performance. These values can also be used to determine the thickness of the surface layer required to achieve a set structural capacity.

*Original Design*

The original design layers and thicknesses are shown in Table 1 below. The structural coefficients for each layer used in the pavement analysis are also shown; these are the standard values that the NHDOT uses for these materials in the design of State roads. The structural number is the structural capacity that the layer contributes to the overall structural capacity of the pavement; it is the product of the thickness and the structural coefficient. The overall structural capacity of the pavement is represented by the total structural number, which is the sum of the structural numbers from all pavement layers. The original design called for the use of crushed gravel and gravel material in the base and subbase layers, respectively.

Approved materials (shop drawings) allowed for the substitution of crushed fine and coarse stone for the base and subbase layers. The material properties for the shop drawing approved pavement design layers and thicknesses are shown in Table 2. The crushed stone that was approved via shop drawing results in a total structural number that is about 30% higher than that of the original design. The approved shop drawing materials and pavement layers (Table 2) are used for comparison with the constructed structure in the following section.

Based on the pavement analysis and design assumptions, the number of standard axle loadings (18 kip) until failure for the whole pavement structure (shop drawing approved materials) and the pavement structure without the surface layer are expected to be:

Whole structure = 174 million Without surface layer = 74.2 million

The pavement without the surface layer has only a fraction (43%) of the capacity of the full pavement structure because of the significant contribution of the top layer to the overall structural number for the pavement.

Table 1. Original Design Pavement Materials and Properties

| Layer | Material | Thickness | Structural Coefficient | Structural Number |
|---|---|---|---|---|
| Surface | 12.5mm HMA | 1.5 | 0.38 | 0.57 |
| Binder | 19 mm HMA | 3.5 | 0.38 | 1.33 |
| Base | 304.3 crushed gravel | 12 | 0.10 | 1.20 |
| Subbase | 304.2 gravel | 12 | 0.07 | 0.84 |
| | | | TOTAL Structural Number | 3.94 |

Table 2. Shop Drawing Approved Pavement Materials and Properties

| Layer | Material | Thickness | Structural Coefficient | Structural Number |
|---|---|---|---|---|
| Surface | 12.5mm HMA | 1.5 | 0.38 | 0.57 |
| Binder | 19 mm HMA | 3.5 | 0.38 | 1.33 |
| Base | 304.4 cr stone fine | 12 | 0.14 | 1.68 |
| Subbase | 304.5 cr stone coarse | 12 | 0.14 | 1.68 |
| | | | TOTAL Structural Number | 5.26 |

*Constructed Pavement Structure*

The average as-built thickness for the asphalt layer was calculated using reported yield values from construction records. The layer average as-built thicknesses for the gravel layers, with the exception of Phase VIII, was measured from 27 borings, nine cores, and three test pits. All as-built thicknesses are shown for each project phase in Table 3 below. The last section, phase VIII, contained a reclaimed base (instead of full box construction), so this phase was not included in the comparative analysis. Also shown is the average for all of the phases. The thickness of the base and subbase layers are combined due to difficulty in distinguishing between the two materials during the forensic testing in the field.

The pavement analysis was performed for two cases:

1. This case examines the impact of layer thickness only. The full NHDOT structural coefficient values for the shop drawing approved materials shown in Table 2 above are used; no adjustments were made for density variation, asphalt content, variations in gradation of the mixture or base materials, or pavement cracking. Average as-built thicknesses for both the HMA and gravel layers, as shown in Table 3, were used. The analysis results for this case are shown in Table 4.
2. This case examines the impact of issues with the HMA layer only and may be a more reasonable approach based on the measurement tolerances for the gravel layer and the fact that the cracking manifested itself so quickly during the winter when the gravel layer was frozen and differences in thickness of the gravel layer would have minimal impact on the overall structural capacity of the pavement. Adjusted structural coefficient values, as shown in Table 5, were used for the HMA layer to account for the brittle mixture and cracking that exists in each phase. Average as-built thicknesses for the HMA layer were used and the gravel layer was assumed to be a constant 24 inches with a structural coefficient value of 0.14. The analysis results for this case are shown in Table 6.

Case 1:

The first row of Table 4 shows the number of standard axle loadings until failure without the surface course. The second row shows the percentage of loads that the constructed section will withstand relative to the shop drawing approved design without the surface course (74.2 million load capacity). The third row shows the thickness of the surface layer that would be required to obtain the same performance of the shop drawing approved design structure (174 million load capacity). As shown, there is significant variation in the expected performance of different sections of the roadway based on the constructed thicknesses. Some areas need little to no additional thickness in the surface layer (phases IIa and IIb) whereas other areas (phases I, IIIa, IV, V) need an additional ¾ inch or more of surface layer material to ensure performance similar to that in the shop drawing approved design.

Case 2:

The HMA structural coefficient values for all phases were first reduced by 0.02 (to a value of 0.36) to account for the brittleness of the HMA due to the combination of measured PG grade, low asphalt content, and high fines in the mixture. The measured distresses (in-lane and centerline cracking) in linear percentage were converted to area percentages by assuming 11 ft lane widths, 1 ft centerline width, and 2 ft wheel path width, as shown in Table 5. The structural coefficient value for each phase was then reduced based on the percentage of cracked area. A maximum value of 0.36 was used in phases with minimal cracking and a minimum value of 0.30 was used in phases with the most cracking. The adjusted structural coefficient values were based on the recommendations published by FHWA (http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/05c.cfm) and shown in Figure 1. The structural coefficient values used for each phase in the Case 2 analysis are summarized in Table 5.

The measured gravel thicknesses in Table 3 were reported to have a tolerance of ± 2 inches. To account for possible measurement errors in the gravel tolerances, a constant gravel thickness of 24 inches (equivalent to the design thickness) was used for all phases in this analysis.

The first row of Table 6 shows the number of standard axle loadings until failure without the surface course. The second row shows the percentage of loads that the constructed section will withstand relative to the shop drawing approved design without the surface course (74.2 million load capacity). The third row shows the thickness of the surface layer that would be required to obtain the same performance of the shop drawing approved design structure (174 million load capacity). As shown, there is some variation in the expected performance of different sections of the roadway based on the HMA layer thicknesses and cracking in each phase, but the thicknesses are more consistent along the corridor than in Case 1. Some areas need little additional thickness in the surface layer (phases IIb and VII) whereas other areas (phases IIIa and IIIb) need more than an additional ½ inch of surface layer material to ensure performance similar to that in the shop drawing approved design.

Table 3. Average Measured Constructed Layer Thicknesses Used in Case 1 Analysis

| Layer | Material | Thickness | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IIb | IIa | I | IIIa | IIIb | IV | VII | V | VI | VIII |
| Surface[a] | 12.5mm HMA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Binder[b] | 19 mm HMA | 4.0 | 3.3 | 3.5 | 3.2 | 3.8 | 3.6 | 3.4 | 3.5 | 3.4 | -[c] |
| Base<br>Subbase | 304.4 cr stone fine<br>304.5 cr stone coarse | 26.0 | 23.7 | 22.0 | 22.4 | 22.4 | 19.3 | 22.3 | 20.0 | 23.3 | - |

[a]surface layer has not been placed
[b]binder thicknesses based on yield calculations
[c]reclaimed base, section not included in analysis

Table 4. Case 1: Constructed Pavement Analysis Using Full NHDOT Structural Values and Average Measured HMA and Gravel Layer Thicknesses

| | IIb | IIa | I | IIIa | IIIb | IV | VII | V | VI | VIII* |
|---|---|---|---|---|---|---|---|---|---|---|
| # loads (million) | 151 | 61.8 | 46.1 | 43.2 | 62.4 | 27.7 | 47.8 | 29.8 | 59.2 | n/a |
| % of shop drawing approved design (considering no surface layer) | 203% | 83% | 62% | 58% | 84% | 37% | 64% | 40% | 80% | |
| required surface thickness (in) to get same structural number as the shop drawing approved design | 0.26 | 1.81 | 2.29 | 2.39 | 1.79 | 3.09 | 2.23 | 2.97 | 1.88 | |

*section VIII contains reclaimed base and was not analyzed

Table 5-44. Suggested layer coefficients for existing flexible pavement layer materials (AASHTO, 1993).

| Material | Surface Condition | Coefficient |
|---|---|---|
| AC Surface | Little or no alligator cracking and/or only low-severity transverse cracking | 0.35 - 0.40 |
| | <10% low-severity alligator cracking and/or<br><5% medium- and high-severity transverse cracking | 0.25 - 0.35 |
| | >10% low-severity alligator cracking and/or<br><10 percent medium-severity alligator cracking and/or<br>>5-10% medium- and high-severity transverse cracking | 0.20 - 0.30 |
| | >10% medium-severity alligator cracking and/or<br><10% high-severity alligator cracking and/or<br>>10% medium- and high-severity transverse cracking | 0.14 - 0.20 |
| | >10% high-severity alligator cracking and/or<br>>10% high-severity transverse cracking | 0.08 - 0.15 |
| Stabilized Base | Little or no alligator cracking and/or only low-severity transverse cracking | 0.20 - 0.35 |
| | <10% low-severity alligator cracking and/or<br><5% medium- and high-severity transverse cracking | 0.15 - 0.25 |
| | >10% low-severity alligator cracking and/or<br><10% medium-severity alligator cracking and/or<br>>5-10% medium- and high-severity transverse cracking | 0.15 - 0.20 |
| | >10% medium-severity alligator cracking and/or<br><10% high-severity alligator cracking and/or<br>>10% medium- and high-severity transverse cracking | 0.10 - 0.20 |
| | >10% high-severity alligator cracking and/or<br>>10% high-severity transverse cracking | 0.08 - 0.15 |
| Granular Base/Subbase | No evidence of pumping, degradation, or contamination by fines | 0.10 - 0.14 |
| | Some evidence of pumping, degradation, or contamination by fines | 0.00 - 0.10 |

Figure 1. FHWA Suggested Layer Coefficients for Existing HMA Layers (http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/05c.cfm)

Table 5. Adjusted HMA Structural Coefficient Values Used in Case 2 Analysis

| Parameter | Phase | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | IIb | IIa | I | IIIa | IIIb | IV | VII | V | VI |
| Measured in-lane (I/L) cracking (linear %) | 0 | 1.4 | 1.3 | 38 | 18 | 0 | 5 | 1.1 | 0 |
| Measured centerline (C/L) cracking (linear %) | 100 | 28 | 63 | 67 | 100 | 100 | 10 | 41 | 7 |
| % area cracking (assumes 11' lanes, wheel path width =2', centerline width = 1') | 4.55 | 1.40 | 2.98 | 6.50 | 6.18 | 4.55 | 0.91 | 1.96 | 0.32 |
| Adjusted structural coefficient value (0.3-0.36 range) | 0.31 | 0.35 | 0.33 | 0.30 | 0.30 | 0.31 | 0.35 | 0.34 | 0.36 |

Table 6. Case 2: Constructed Pavement Analysis Using Adjusted HMA Structural Values, Table 3 HMA Thicknesses and 24" Gravel Thickness

| | IIb | IIa | I | IIIa | IIIb | IV | VII | V | VI | VIII* |
|---|---|---|---|---|---|---|---|---|---|---|
| # loads (million) | 66.3 | 55.1 | 54.9 | 39.9 | 54.3 | 55.2 | 59.8 | 59.6 | 61.8 | n/a |
| % of shop drawing approved design (considering no surface layer) | 89% | 74% | 74% | 54% | 73% | 74% | 81% | 80% | 83% | |
| required surface thickness (in) to get same structural number as the shop drawing approved design | 1.69 | 2.00 | 2.00 | 2.52 | 2.02 | 1.99 | 1.86 | 1.87 | 1.81 | |

*section VIII contains reclaimed base and was not analyzed

### Assessment of Remedial Repair Options

The two primary repair options are A) removal and replacement of the existing asphalt concrete binder layer followed by the planned surface layer and B) repair of cracked areas and overlay with a surface layer. The final structural capacity of the pavement is equivalent under both options.

A. Removal and replacement would allow for remediation of the thickness and potential material deficiencies, but would be very costly, time consuming, disruptive, and the new materials would be subject to construction variation and tolerances. It is likely that this option, with the additional oversight that would occur, would result in more consistent pavement cross section along the project. However this difference would not likely result in a significant impact on performance for the project overall.

B. Repair of cracked areas (using a fabric) and overlay with the surface layer would allow for remediation of structural deficiencies by adding additional thickness to the pavement structure in areas where it is currently deficient. A thicker surface layer will compensate for the thinner constructed base and binder layers. Although this option does not allow for replacement of the existing binder asphalt concrete layer, the addition of the surface layer will decrease the stresses that the binder layer experiences, and hence the binder layer will be less likely to crack. The additional thickness should be made up with the structural asphalt concrete mix as opposed to shim material; shim material is not detrimental to the pavement structure and will help to provide some additional resistance to the load, but would not be placed at a consistent thickness in all areas and is therefore not considered in the pavement analysis.

   A combination of factors that includes lower asphalt content, higher fines content, and stiffer asphalt cement has likely created a more brittle asphalt mixture in the binder layer. The thicknesses shown in Table 6 are the recommended minimums to ensure the finished pavement has performance similar to that in the shop drawing approved design. This approach is equivalent to treating the existing as-built structure like an older road (that would have a more brittle surface due to aging over time) and placing an overlay as a rehabilitation strategy to extend the life of the pavement before a full reconstruction is required. This option will be subject to construction variation and tolerances for the surface layer but will be less costly, time consuming, and disruptive than option A. It is likely that this option, with the additional oversight that would occur, would result in a pavement that would be expected to have similar performance to the one that was originally designed and approved via shop drawing.

### Suggestions for Future

It is suggested that NHDOT recommendations for QC/QA be followed for either repair option described above due to the importance of this project. In the future, it is recommended that an appropriate QC/QA plan be developed for each project that balances the importance of the project and risk of failure similar to the one observed on Tolend road. Specifically, attention to layer thicknesses and densities should be increased which may necessitate a change in allowable tolerances. Also, 50 gyration asphalt mixtures should be specified instead of 75 gyration mixtures and QC/QA testing should include verification of asphalt content and mixture gradation.